Residual Stress Measurement in GaN Deposited on Sapphire Substrate

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Abstract

GaN recently has received much attention as a semiconductor which is applicable for optical devices including light emitting diodes (LED) and lasers in the blue, violet and near ultraviolet spectral range. Thin films of GaN are usually grown on sapphire substrate by metalorgnic vapor phase epitaxy (MOVPE).

Residual stresses always develop in the films because of differences in atomic distances, thermal expansion coefficients, temperatures and cooling conditions between the film and the substrate. Large residual stresses may cause microcracks in the film or film peeling from the substrate. Therefore, the control of residual stress is essential to synthesize mechanically stable GaN films.

GaN has hexagonal closed-packed structure with lattice parameters a=0.31892 nm and c=0.49798 nm [1]. The structure of GaN film deposited (0001) sapphire substrate by MOVPE is single crystal, and the c-axis of a GaN crystal orients the normal to the surface of substrates. Therefore, the conventional $\sin^2\psi$ method cannot be adopted in the present case. We propose the new analyzing method.

In general, the lattice strain ε^L_{33} in any orientation is related by the following equation to the stress components σ_{ij} in the coordinate system attached to the specimen :

$$\varepsilon^L_{33} = \gamma_{3i}\,\gamma_{3j}\,\pi_{mk}\,\pi_{nl}\,s^c_{ijkl}\,\sigma^s_{mn} = s^L_{33mn}\,\sigma^s_{mn} \qquad (1)$$

where s^c_{ijkl} are elastic compliances of a single crystal, γ_{ij} the components of the transformation matrices form the crystal system to the laboratory system and π_{ij} those form the crystal system to the specimen system.

If we assume that the state of stress is equi-biaxial state, i.e., $\sigma^s_{11} = \sigma^s_{22} = \sigma$ and other σ^s_{ij} are zero, Eq. (1) is then reduced to

$$\varepsilon^L_{33} = \{(s^c_{11} + s^c_{12} - 2\,s^c_{31})\sin^2\psi + 2\,s^c_{31}\}\,\sigma \qquad (2)$$

where s^c_{ij} are elastic compliances of the single crystal in a matrix notation and ψ is equal to the angle between (00·1) plane and each (hk·l) plane. Table 1 shows the diffraction planes used in the present study, their Bragg angles, their arising angles in ψ and the values of $\sin^2\psi$.

Equation (2) means that the lattice strain for each (hk·l) plane relates linearly with $\sin^2\psi$. Therefore, if we could measure a set of hk·l diffraction, strains for each diffraction plane should lie on a straight line. From the slope of the line determined by the least square method, stress value can be estimated under a knowledge of the value of $(s^c_{11} + s^c_{12} - 2\,s^c_{31})$ by the following relation :

$$\sigma = \left(s^c_{11} + s^c_{12} - 2s^c_{31}\right)^{-1} \frac{\partial\,\varepsilon^L_{33}}{\partial \sin^2\psi} \qquad (3)$$

where s^c_{ij} for GaN crystal are; s^c_{11}=5.10×10^{-6} / MPa , s^c_{12}= -0.92×10^{-6} / MPa and s^c_{31}= -2.48×10^{-6}

/MPa [2].

Table 1 Diffraction planes and related parameters.

hk·l	2θ (deg)	ψ (deg)	$\sin^2\psi$
10·1	56.1	61.9	0.78
10·2	74.7	43.2	0.47
10·3	103.0	32.0	0.28
00·4	124.4	0.0	0
10·5	155.3	25.1	0.18

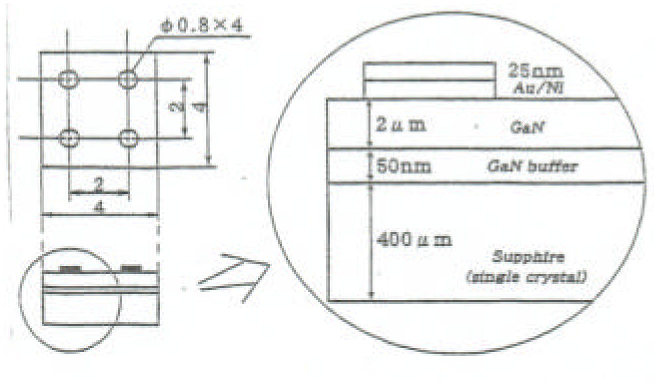

Fig.1 Sample of GaN film.

Figure 1 shows a schematic diagram of the sample. GaN film was deposited on (0001) sapphire by MOVPE and the film thickness was about 2μm. Next, four electric terminals were set on the GaN film surface. The diameter of electric terminals was 0.8 mm and the distance between two electric terminals was 2 mm. We measured residual stress in GaN film between the electric terminals. CrKα characteristic X-rays were utilized and the diameter irradiation area was about φ=0.35 mm.

Figure 2 shows example of lattice strain vs. $\sin^2\psi$ measured from the center between the electric terminals. The slope of a obtained line was negative. Therefore, residual stress in the GaN film was compressive and the value was about -1.2 GPa. Figure 3 shows residual stress distribution between the electric terminals. Compressive stress of about -1.2 GPa was obtained for all positions.

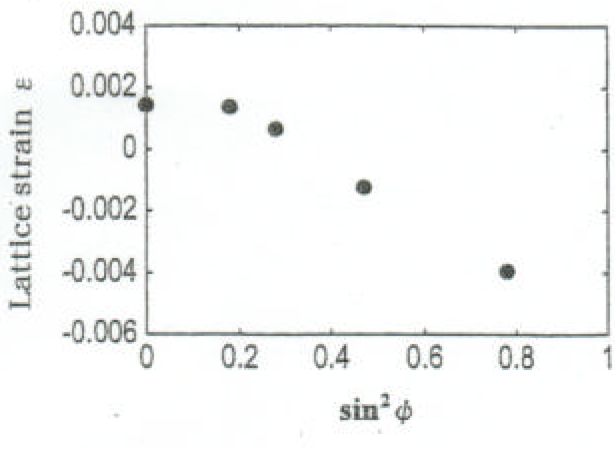

Fig. 2 ε-$\sin^2\psi$ diagram

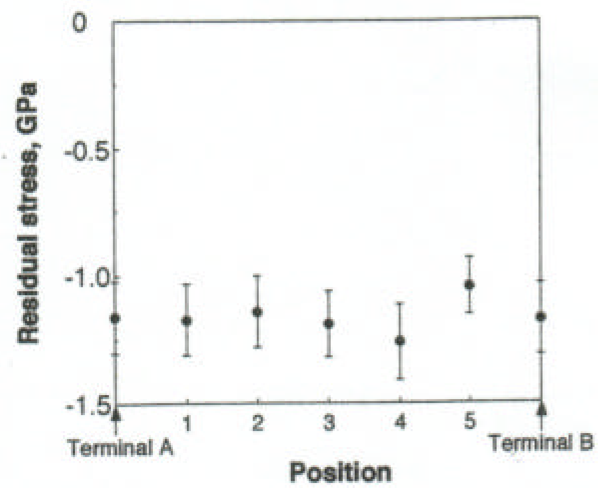

Fig.3 Residual stress distribution between the electric terminals

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